The ISS Dynamic Lighting Schedule: An In-Flight Lighting Countermeasure to Facilitate Circadian Adaptation, Improve Sleep and Enhance Alertness and Performance on the International Space Station

Completed Technology Project (2012 - 2015)

Project Introduction

Spaceflight often exposes crews to unusual sleep-wake and work schedules that lead to misalignment of the circadian pacemaker, including abrupt slam-shifts of work hours into the night, or entrainment to unusual day-lengths (e.g., 24.65 h Martian sol), resulting in poor sleep, impaired alertness, and increased risk of fatigue-related accidents. Untreated circadian misalignment results in sleep and wake occurring at the incorrect circadian phase which reduces sleep quality and quantity and impairs alertness, reaction time, and cognition. Even without circadian misalignment, sleep duration is usually poor (~6 h/night) during spaceflight and hypnotic medications and caffeine are commonly used to address insomnia and daytime sleepiness. In such a high-risk environment as the International Space Station (ISS), the risk of sleepiness-related performance decrements and accidents must be minimized. Light is a potential powerful countermeasure for both circadian misalignment and sleepiness associated with spaceflight. The effects of light are non-pharmacological and safe and can be obtained from ambient lighting.

Recently, we and others have shown that short-wavelength (blue) light is most effective for phase-shifting the circadian pacemaker and enhancing alertness and performance. In addition to permitting vision, manipulation of short-wavelength blue light in particular has the potential to be a safe, non-pharmacological countermeasure to reduce the risk of circadian misalignment and performance deficits during spaceflight. These benefits can be achieved either by enhancing blue light to increase circadian resetting and alerting responses when required, for example when adapting to a slam-shift, or depleting blue light to minimize the effects of light when these responses are not required, for example prior to sleep. Using blue light per se, however, is undesirable as it impairs visual function, an important consideration in spaceflight. Manipulation of the blue light content of white light has similar benefits, however, and provides a way to optimize both the visual and non-visual responses simultaneously.

A unique opportunity has arisen with the need to replace the current lighting aboard the International Space Station. NASA has proposed a new solid state lighting system with three pre-determined settings to address different operational needs: 1) white light for general vision; 2) blue-enriched white light to enhance high circadian adaptation and alertness; 3) blue-depleted white light to minimize alertness prior to sleep. We have developed a Dynamic Lighting Schedule (DLS) which determines when each of these three settings will be used to optimize lighting to maintain visual function and as a countermeasure to facilitate circadian adaptation, improve alertness and performance, and enhance sleep. The current proposal will study how the new lights would be deployed to address the problems associated with a simulated slam shift, in a high-fidelity analog of the ISS lighting environment, sleep

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patterns, and work schedule. In two 8-day randomized clinical trials, we tested the hypotheses that deployment of the DLS could increase the rate of circadian adaptation, improve sleep, and improve cognitive performance, subjective alertness, and objective EEG correlates of alertness.

Experiment 1a examined 8-hour phase advance shifts and compared the effect of a continuous 6.5 h exposure to the DLS following a gradual versus immediate ('slam') shift in the sleep-wake cycle (n=18). Experiment 1b examined 8-hour phase delay shifts and compared the effect of a continuous 8 h exposure to the DLS to a standard lighting control following a slam shift in the sleep-wake cycle (n=12). Analysis of Experiment 1a showed that there was no statistical difference in phase shifting between gradual and slam advancing protocols, both achieving ~2.5 h of phase advance. Preliminary analyses of Experiment 1b suggest significantly greater phase delays induced by the DLS method compared to control. Analyses of the sleep and performance outcome measures are ongoing. These data will form the basis of operational lighting recommendations for use of the Solid State Lighting Assemblies (SSLA) aboard ISS when deployed in 2016-2017.

Anticipated Benefits

Light exposure is a requirement for all spaceflight and base missions and careful consideration is required to provide light of sufficient quality and quantity to ensure adequate vision and to optimize the circadian, neuroendocrine, and neurobehavioral effects of light, and ultimately crew health and safety. The requirement to replace the out-of-date fluorescent lighting onboard ISS has provided an opportunity to re-fit the ISS with the latest in solid-state lighting technology which has the capability to provide light of varying spectrum, intensity, and pattern. While ours and others' work has established blue and blue-enriched light as optimal to enhance circadian entrainment and alertness, final ground-based testing in high-fidelity analogs is required to develop guidelines for operational use prior to flight testing. The proposed study will provide the ground-based data necessary to inform guidelines for flight testing the new lighting source, in time for the fluorescent light replacement in 2015. The proposal specifically targets lighting countermeasures to address circadian misalignment and performance decrements during a slam-shift, which is a common requirement during Soyuz docking, and to enhance sleep and alertness during both slam-shift and normal operations. Without such data, future recommendations for operational deployment of the Solid State Lighting Assemblies (SSLAs) will be suboptimal. The Earth-based applications and commercialization potential of these studies are enormous. The slam-shifts aboard ISS, and the consequences to sleep, circadian rhythms, performance, and health, are very similar to that experienced by the 15M Americans who do shiftwork. The World Health

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Organization:

National Space Biomedical Research Institute (NSBRI)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Principal Investigator:

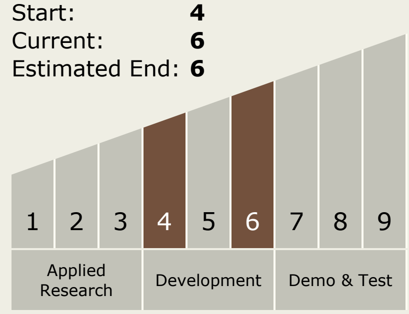
Steven W Lockley

Co-Investigator:

Charles A Czeisler

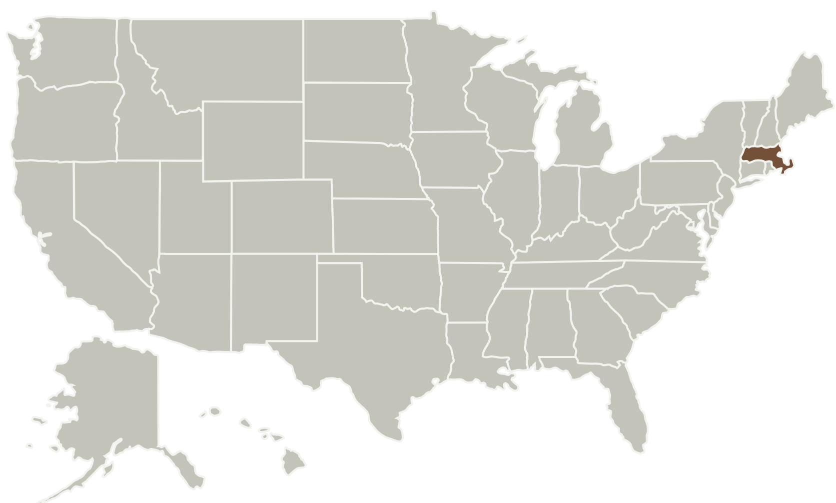
Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Organization recently designated shiftwork that involves circadian desynchrony as a probable carcinogen and shift-workers also have high rates of night-time accidents and injuries, cardiovascular disease, and diabetes. Similar lighting interventions could be deployed for night shift-workers using the same Dynamic Lighting Schedule (DLS) which would have the benefit of improving productivity and safety while also reducing energy use by using targeted light spectra that only provide the light needed. Many non shift-workers also suffer circadian misalignment and performance problems, for example the early-riser workforce, school and college students, professions requiring long work hours etc., and would benefit from a similar DLS. Patients in hospitals and care homes are also often exposed to poor light-dark patterns, correction of which has recently been shown to slow the rate of cognitive decline in dementia. Anywhere where high levels of alertness, performance, and vigilance are required are target sites for such lighting interventions and provide enormous potential for commercialization.

Primary U.S. Work Locations and Key Partners



Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  └ TX06.3 Human Health and Performance
    └ TX06.3.3 Behavioral Health and Performance

Target Destinations

The Moon, Mars

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Organizations Performing Work	Role	Type	Location
National Space Biomedical Research Institute(NSBRI)	Lead Organization	Industry	Houston, Texas
Brigham And Women's Hospital, Inc.	Supporting Organization	Industry	Boston, Massachusetts

Primary U.S. Work Locations
Massachusetts

Project Transitions

October 2012: Project Start

October 2015: Closed out

Closeout Summary: We began our recruitment efforts in Jan 2013 and we have successfully completed all planned studie s. Thirty participants have completed the 8-day inpatient protocol out of whom 18 were studied in the first (advance) arm o f Experiment 1a and 12 in the second (delay) arm of Experiment 1b. A total of 5 participants were admitted but then disem panelled from the study. The analyses for Aim 1 are complete. The analyses for Aims 2 and 3 are near-completion. Final cle aned and complete datasets are available and analyses are ongoing. We anticipate presentation of the final analyses for all aims at the 2016 Human Research Program Workshop and submission of the final manuscript shortly thereafter.

Stories

Abstracts for Journals and Proceedings
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Project Website:

https://taskbook.nasaprs.com